Leaf litter invertebrate assemblages in box-ironbark forest: composition, size and seasonal variation in biomass

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Abstract

Ground-dwelling invertebrates are an important component of the box-ironbark forest ecosystem, but have been relatively little studied. This study quantified the composition, size and seasonal variation in biomass of leaf litter invertebrates in a box-ironbark forest in Victoria over a period of two years. Invertebrates were extracted using Tullgren funnels in one year and by hand-sorting in a subsequent year. Seven classes of arthropod were identified. Hymenoptera was the most numerous taxon comprising 22% and 29% of the invertebrates extracted in each year. Most invertebrates were small: 81% extracted using Tullgren funnels (minimum length 0.1 mm) and 77% extracted by hand-sorting had a body length of less than 5.0 mm. There was significant seasonal variation in the biomass of the leaf litter invertebrates, with a short peak of one to two months' duration from the end of winter, that is, at the end of the coldest and wettest period of weather. The time of lowest biomass was during the summer months (December, January and February), the hottest and driest period of the year. The biomass of leaf litter invertebrates was significantly correlated with the moisture content of the leaf litter. (*The Victorian Naturalist* **125** (1), 2008, 19-27)

Introduction

At the beginning of the 19th century, box-ironbark forest was the dominant vegetation type along the inner slopes of the Great Dividing Range from Victoria to central New South Wales and covered approximately 1 million hectares. Between 75% and 85% of the original cover has been cleared (Calder *et al.* 1994; Victorian National Parks Association VNPA 1999). Surviving remnants are highly fragmented and severely altered in structure through a combination of firewood and timber collection, mining, inappropriate burning and livestock grazing (Bennett 1993; Calder 1993; Robinson 1993; Sivertsen 1993; Traill 1993; Bromham *et al.* 1999). Few large old trees remain and the understorey and ground layers have been degraded with little decomposing timber on the ground.

Box-ironbark forests typically have a diverse flora and fauna, including many rare and threatened species. Ground-dwelling invertebrates play essential roles in the decomposition of organic material and the cycling of nutrients, and are the base of the food chain for many vertebrates (Yen *et al.* 1999). At least 15 species of box-ironbark forest birds, including the White-winged Chough *Corcorax melanorhamphos*, White-browed Babbler *Pomatostomus superciliosus* and robins *Petroica* spp. and *Eopsaltria australis*, are ground-foragers, depending mainly on leaf litter invertebrates (Laven and Mac Nally 1998). White-browed Babblers spent 95% of their foraging time on the ground searching amongst leaf litter for invertebrate prey (Taylor 2003).

Because of their importance for insectivorous, ground-foraging vertebrates and their broad influence within the box-ironbark ecosystem, information on leaf litter invertebrates is essential for an ecological understanding of box-ironbark forests and their management. Despite this there are relatively few published studies. An initial investigation of the diversity of ground-dwelling invertebrates across the box-ironbark region in Victoria yielded 35 orders and quantified their relative abundance (Yen *et al.* 1999). However, there have been no detailed studies of the size distribution of ground-living invertebrates or of their seasonal variation in abundance, although leaf litter invertebrate abundance and diversity have been examined in relation to human interference in Grey Box *Eucalyptus microcarpa* woodland in Victoria (Bromham *et al.* 1999). The identification of seasonal changes in abundance of invertebrates in eucalypt forests and woodlands in general has proved difficult because of the diversity of organisms, the variety of short-term and long-term environmental influences on abundance and year to year variation (Ford 1985).

This study examined the composition, size and seasonal variation in the biomass of leaf litter invertebrates in a box-ironbark forest. Temperature and rainfall were recorded to allow comparison with seasonal changes in the biomass of the invertebrates.

Methods

Study area

The study took place within the box-ironbark forest of Chiltern-Mount Pilot National Park in north-eastern Victoria (36°10′S, 146°37′E). This forest type occurred in a 4320 ha northern section of the park and is the most north-easterly representation of box-ironbark forest in Victoria. The vegetation is dry sclerophyll, open forest mostly comprising two Ecological Vegetation Classes: 'Box-Ironbark Forest' and 'Heathy Dry Forest' (Muir *et al.* 1995). The eucalypt species are Red Ironbark *Eucalyptus sideroxylon*, Red Stringybark *E. macrorhyncha*, Blakely's Red Gum *E. blakelyi* and boxes: Red Box *E. polyanthemos*, Grey Box *E. microcarpa*, White Box *E. albens*, Long-leaved Box *E. goniocalyx* and Apple Box *E. bridgesiana*. These form an open canopy about 20-30 m high. The nature and extent of the understorey vegetation is variable but is generally sparse (less than 6% cover by area) (Taylor 2003) and mostly comprises Cherry Ballart *Exocarpus cupressiformis* and wattles *Acacia* spp., particularly Golden Wattle *A. pycnantha*. In some areas there are smaller shrubs, low herbaceous plants and/or grasses. The leaf litter is generally sparse and shallow (less than 2 cm deep).

The area was subjected to extensive and intensive alluvial and quartz reef gold mining in the mid to late 1800s when the forest was mostly clear-felled, with many of the remaining mature trees removed in the 1950s and 1960s (Meredith 1984). Thus the present forest is re-growth and relatively immature. The topography is undulating with broad gullies, rises and several prominent ridges. The altitude ranges from 180 m to 390 m asl. However, this study was restricted to elevations below 290 m as it was carried out to provide information on the food supply of the White-browed Babbler, which does not occur above this altitude (Taylor 2003). The climate is Mediterranean with hot, dry summers and cool winters.

Quantification of invertebrate abundance

The abundance of leaf litter invertebrates was quantified over a period of two years: the first using Tullgren funnels and the second using hand-sorting in the field.

In the Tullgren funnel extraction, fifteen leaf litter samples were taken every second month from June 1999. Randomly selected co-ordinates determined the location of each sample.

A 0.25 m^2 quadrat, comprising four 50 cm lengths of plywood of height 10 cm, was placed gently to minimise disturbance to the invertebrates. Invertebrates disturbed in the process were gathered into plastic tubes before all the leaf litter within the quadrat was scraped up by hand and placed within sealed bags. Each sample was weighed (± 1 g) in the field using a Pesola balance.

The leaf litter samples were placed in Tullgren funnels for extraction of the invertebrates within one to five hours after collection. The extraction set-up comprised 30 cm long metal cylinders with a grid base of 15 cm diameter. Each sample was extracted separately using as many cylinders as were required to hold the litter loosely. Each cylinder was placed in a plastic funnel leading to a tube containing 80% ethanol for preserving the invertebrates and closed with a lid from which a 60 W globe hung such that it was within 5-10 cm of the leaf litter. Samples were left under the lights for approximately 48 hours to give sufficient time to extract the invertebrates (New 1998).

The dry weight of each leaf litter sample was determined by oven drying a weighed (± 0.01 g) sample at 100°C until constant weight (six to eight hours). The moisture content of the original sample from each quadrat was then determined by subtraction from the wet weight.

The extracted invertebrates were sorted under a binocular microscope. Body length of invertebrates ≥ 1.0 mm was measured to the nearest 0.1 mm using a minigrid. This measure excluded the lengths of any antennae and wings where they extended beyond the head and abdomen. Invertebrates were classified to order except for Collembola, Protura, Chilopoda and Diplopoda that were identified only to class. Invertebrates of body length < 1.0 mm were not identified, but total counts were made.

Invertebrate abundance was determined by hand-sorting for one year from March 2001. Searching by hand is a reliable, basic method for determining invertebrate abundance and is less time consuming than the Tullgren funnel method (New 1998). Sampling was carried out monthly on fine, clear or only partially cloudy days as it was easier to search the sample in sunshine. Fifteen sample quadrats of leaf litter, also 0.5 m x 0.5 m, were taken each month from a 15 ha section in the north of the park. After initial removal of large, conspicuous invertebrates the remaining leaf litter was sorted systematically in a large (50 cm x 40 cm), high-sided white plastic tray. A searching time of 20 seconds per 10 g of leaf litter was used. The time spent sorting had to be sufficient to obtain the majority of invertebrates in the sample and needed to be standardised such that the search effort was constant for samples containing different amounts of litter. To determine the time needed, 25 samples of leaf litter were sorted by hand and the time of capture of each invertebrate was recorded. When sorting leaf litter samples for a duration of 20 seconds per 10 g of leaf litter, 90% of the total number of invertebrates extracted had been found after 70% of the sampling time had passed. This suggested that searching time would have to have been increased considerably to find the remaining invertebrates. With an error of only 5% of biomass this compromise was considered acceptable (see below). Searching was restricted to invertebrates of ≥ 2.0 mm long, which were classified to the level of order and their lengths measured to the nearest 0.1 mm (as above).

To determine the number of invertebrates not collected during the hand-sorting method, and to calibrate hand-sorting with the Tullgren funnel extraction method, the samples for April 2001 were first sorted by hand before remaining invertebrates were extracted using Tullgren funnels: 24.8% of invertebrates ≥ 2.0 mm were not extracted using the hand-sorting method. However, as most of these (57%) were small (< 3.0 mm), the mean percentage of dry mass of invertebrates not extracted from the leaf litter samples using the hand-sorting method was only 5.0% ± 1.2%.

Weekly maximum and minimum temperatures were recorded for one year from the beginning of February 2002. A thermometer was placed in the shade, 2 m above ground level. Rainfall was recorded daily by the rainfall observer at the Chiltern Licensed Post Office located immediately adjacent to the study area.

Analysis

Invertebrate abundance could have been quantified as the density of invertebrates. However, dry mass (biomass) is a better measure of food supply for vertebrates as it takes into account the different sizes of potential prey. Therefore, the dry mass of invertebrates in each sample quadrat was calculated from their lengths using the equation developed by Rogers *et al.* (1976), $W = 0.0305L^{2.62}$, where W is the dry mass in milligrams and L the length in millimetres. The data for dry mass were normally distributed when transformed by $\log(x + 1)$. Analysis of covariance was used to determine seasonal differences in invertebrate biomass with the weight of leaf litter in the sample as a covariate as this also varied seasonally. The moisture content of the leaf litter was expressed as a percentage of the wet weight of the leaf litter. Leaf litter samples collected immediately following rain were excluded from the analyses of seasonal variation in moisture content and the relationship with invertebrate biomass.

Results

Composition of invertebrates in leaf litter samples

The invertebrates collected by both methods were classified into seven arthropod classes: Arachnida, Malacostraca (all Isopoda – woodlice), Chilopoda (centipedes), Diplopoda (millipedes), Insecta, Collembola (springtails) and Protura (proturans). The Arachnida comprised three orders: Araneae (spiders), Acarina (mites) and Pseudoscorpionida (pseudoscorpions);

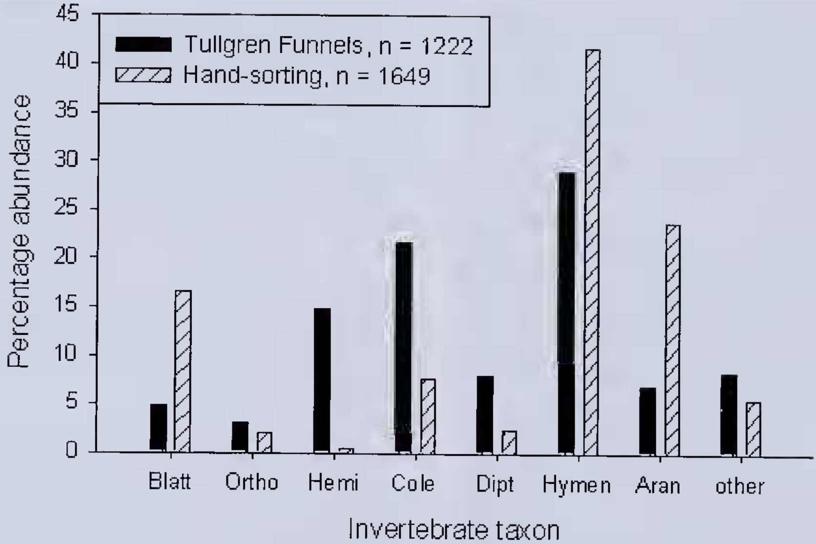

Fig. 1. The percentage abundance (by number) of invertebrates ≥ 2.0 mm by taxon in the leaf litter extracted by the Tullgren funnel method and the hand-sorting method. The taxa are Blattodea, Orthoptera, Hemiptera, Coleoptera, Diptera, Hymenoptera and Araneida. 'Other' includes Collembola, Thysanura, Isoptera, Psocoptera, Thysanoptera, Neuroptera, Lepidoptera, Acarina, Isopoda, Chelinethida, Chilopoda and Diplopoda (all less than 3% each).

and the Insecta 12 orders: Thysanura (silverfish), Blattodea (cockroaches), Isoptera (termites), Orthoptera (grasshoppers and crickets), Psocoptera (psocids), Hemiptera (bugs and leafhoppers), Thysanoptera (thrips), Neuroptera (antlions), Coleoptera (beetles), Diptera (flies), Lepidoptera (moths and butterflies), and Hymenoptera (ants and wasps).

For invertebrates ≥ 1.0 mm long extracted using Tullgren funnels (n = 2 537), Hymenoptera was the most numerous comprising 22% of the total. Of these 97.8% were Formicidae (ants). Collembola (19%) and Coleoptera (19%) were also numerically important, followed by Diptera (11%), Hemiptera (8%) and Araneida, (5%). Remaining taxa each made up less than 3% of the total number. Only 6% of the invertebrates were ≥ 2.0 mm and Hymenoptera was the most numerous (29%, Fig. 1).

Individuals in the four taxa Blattodea, Coleoptera, Hymenoptera and Araneida made up 82% of invertebrates sampled by hand-sorting (n = 1,649, Fig. 1). Hymenoptera was the most numerous (41.7%); all were Formicidae (ants).

Size classes of invertebrates in leaf litter samples

Of the 19 209 invertebrates ≥ 0.1 mm extracted using the Tullgren funnels, 87% were < 1.0 mm. Considering those ≥ 1.0 mm, most (52%) were in the smallest length class of 1.0-1.9 mm (n = 2 537) and 91% were < 5.0 mm.

The frequency distribution of the size classes was similar for invertebrates ≥ 2.0 mm extracted by both methods (Fig. 2). Most, 46% for the Tullgren funnels and 41% for the hand-sorting, were in the smallest length category of 2-2.9 mm while 81% for the Tullgren funnels and 77% for hand-sorting were < 5.0 mm (Fig. 2).

Seasonal variation in the dry mass (biomass) of leaf litter invertebrates

For 1999-2000 (extraction by Tullgren funnels) dry masses were calculated separately for invertebrates ≥ 0.1 mm, and for those ≥ 2.0 mm. Invertebrates < 2.0 mm contributed little to the total dry mass. There was a significant annual variation in the dry mass of leaf litter invertebrates ≥ 2.0 mm body length (ANCOVA with dry weight of leaf litter as a covariate, $F_{(6,84)} = 5.12$, $P < 0.01$, Fig. 3a) with a short peak

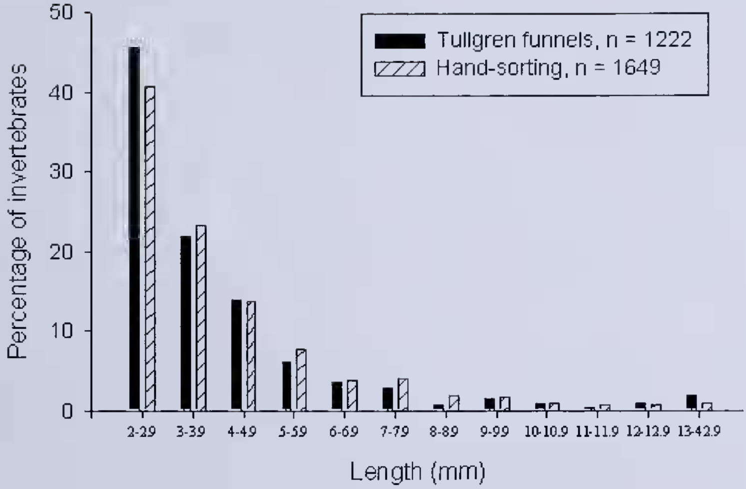

Fig. 2. Frequency distributions of the length classes of invertebrates ≥ 2.0 mm extracted by the Tullgren funnel and hand-sorting methods.

of about two months' duration from the end of winter (late August), and the lowest value was in summer (late December).

For 2001-2002 (hand-sorting) the same general pattern was shown (ANCOVA with wet weight of leaf litter as a covariate, $F_{(12,132)} = 10.06$, $P < 0.001$, Fig. 3b) with a peak in dry mass at the end of winter (late August), and the lowest values during summer (November –February). Values were also low in late autumn (late May).

Moisture content of leaf litter

There was a significant annual variation in the moisture content of the leaf litter (ANOVA of percentage of wet weight (arcsine transformed), $F_{(4,58)} = 6.50$, $P < 0.001$, Fig. 4) which followed a similar pattern as the variation in invertebrate biomass, being highest at the end of winter (late August) and lowest in summer (December). The mean dry mass of invertebrates was significantly correlated with the moisture content of the leaf litter ($r = 0.93$, $P = 0.02$, $N = 5$, Fig. 5).

Temperature and rainfall

In the year from February 2001, weekly minimum temperatures ranged from 0-18°C and maximum temperatures ranged from 11-40°C. Temperatures were highest from December to March and lowest from June to July.

From 1984 to 2002, annual rainfall varied from 418.4 mm to 1039.0 mm with a mean of 720.9 ± 33.5 mm. From 1999 to 2002 monthly rainfall was highly variable (0.0 mm – 124.6 mm), but generally winter months had more rainfall than summer months. During the two years of the invertebrate sampling, winter rainfall was 206.8 mm and 120.0 mm and summer rainfall was 169.4 mm and 109.6 mm, respectively.

Discussion

The compostition of leaf litter invertebrates in the present study can be compared with an investigation of the diversity of ground-dwelling invertebrates using pitfall traps at 80 sites (including the present site) across the box-ironbark region in Victoria (Yen *et al.* 1999). In both studies Hymenoptera was the most numerous taxon and for invertebrates extracted using the Tullgren funnels, Coleoptera, Diptera, Hemiptera and Araneida followed in the same order of percentage abundance in both studies, but Collembola were also numerically important in the present study. In the hand-sorting method Blattodea also had a high relative abundance. These differences are likely to have arisen from the different sampling methods used. Pitfall traps are not reliable for measuring absolute abundance as the composition of the catch is influenced by the susceptibility

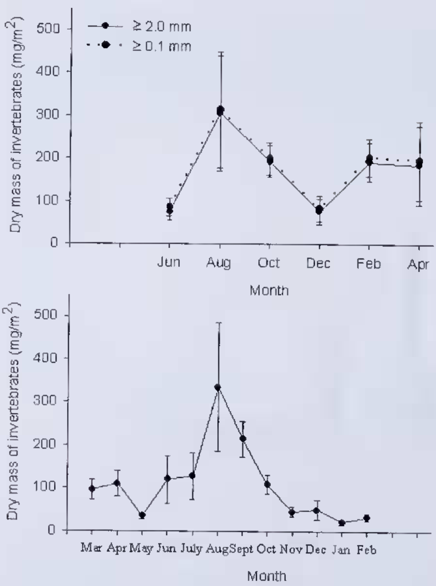

Fig. 3. The annual variation in the mean dry mass of leaf litter invertebrates (± 1 S.E.) during two years: a) June 1999 to April 2000 obtained using the Tullgren funnel method and b) March 2001 to February 2002 obtained using the hand-sorting method. For both years the dry mass of invertebrates ≥ 2.0 mm body length is shown and for 1999-2000 the dry mass of all invertebrates ≥ 0.1 mm body length is also shown.

of different types of invertebrates to trapping (Greenslade 1964, Bromham *et al.* 1999). The Tullgren funnel method of extraction might give a more accurate representation of invertebrate community composition, but the efficiency of extraction of invertebrates varies among taxa (Macfadyen 1961, Southwood 1966) whereas hand-sorting has been reported to be particularly useful in recovering invertebrates with low mobility (New 1998), but might be biased towards less cryptic species.

In this study there was a significant seasonal variation in the biomass of the leaf litter invertebrates, with a peak of one to two months' duration from the end of winter, the coolest and wettest period of the year and lowest biomass during the summer, the hottest and driest period.

There are no other published studies of seasonal changes in leaf litter invertebrates in box-ironbark forests and few in other forest types. Leaf litter arthropods had a two to three month peak in biomass during autumn in eucalypt forest in central New South Wales (Ford *et al.* 1990), and in Mountain Ash *E. regnans* forests of Victoria, leaf litter invertebrates were more abundant during winter than summer (Ashton 1975 cited in Loyn 1985). Autumn or winter peaks in abundance,

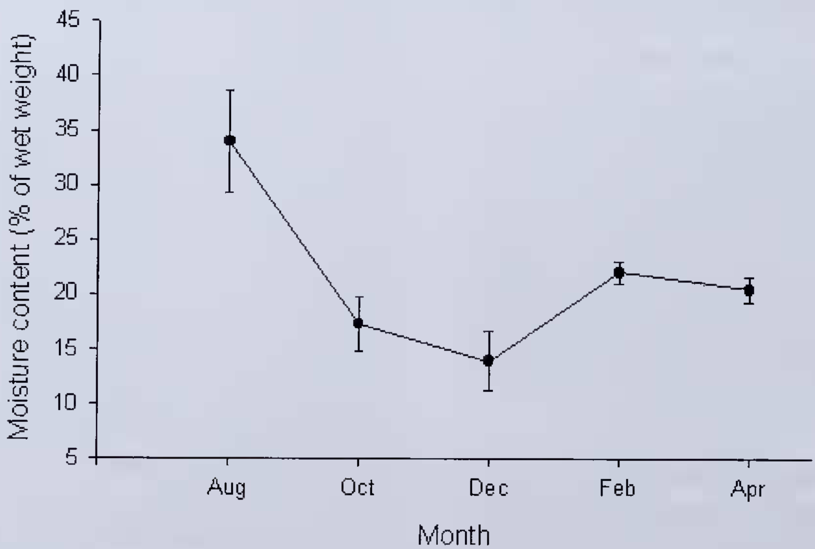

Fig. 4. The annual variation in the moisture content of leaf litter (± 1 S.E.), expressed as the percentage of wet weight of leaf litter, from August 1999 to April 2000.

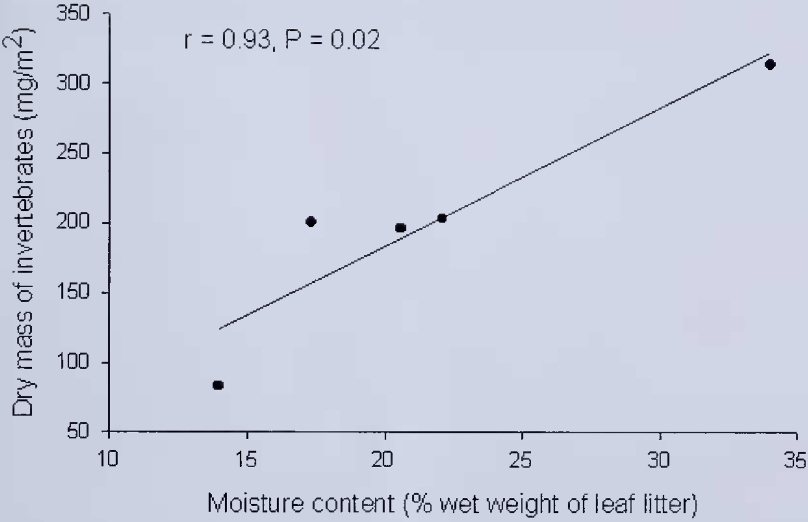

Fig. 5. The variation in the dry weight of leaf litter invertebrates in relation to the moisture content of the leaf litter.

when the leaf litter is relatively moist, and summer lows when conditions are driest, may therefore be a general phenomenon in forests of southern Australia. A summer peak in numbers of ground macroinvertebrates in Grey Box woodland around Benalla, Victoria (Bromham *et al.* 1999) may have reflected invertebrate activity on the surface rather than abundance within leaf litter as pitfall traps were used.

In the present study there was significant seasonal variation in the moisture content of the leaf litter, and invertebrate biomass was significantly correlated with moisture content. In tropical forests of Australia, leaf litter moisture content and arthropod abundance were higher in the wet than in the dry season (Jansen 1997). In Panama abundance was significantly correlated with the moisture content of the litter (Levings and Windsor 1982) and significant increases were recorded on experimentally watered plots (Levings and Windsor 1984). Wet tropical forests in Australia had higher leaf litter invertebrate densities than did dry tropical forests (Plowman 1979). Seasonal and regional variations in the moisture content of leaf litter are therefore probably main factors determining leaf litter arthropod abundance.

The low densities and small sizes of most invertebrates recorded in the present study might suggest that the box-ironbark forest of the study area was a poor quality habitat for ground-feeding insectivorous vertebrates. Direct comparisons with other forests in Australia are difficult as most studies have compared only the relative abundance of selected taxa (Frith and Frith 1990; Bromham *et al.* 1999, Yen *et al.* 1999). Where the absolute abundance (density) has been quantified, biomass has not been calculated. The Berlese funnel extraction technique, comparable to the extraction with Tullgren funnels used in this study, has been used to quantify the density of all invertebrates in several forest types (Table 1). In these studies, the densities of invertebrates were greater than those recorded in the present study, and in most the values were very considerably higher. These comparisons probably represent real differences in densities, but might have been influenced by the size ranges of invertebrates quantified. Lengths below the lower limit of 0.1 mm used in this study might have been included, but details were not provided except in the studies of Jansen (1993, 1997) and that of Cale (1999) in which a hand-sorting method

Table 1. The density of invertebrates extracted from leaf litter from different forest types in Australia using Berlese or Tullgren funnels. Ranges indicate the variation in density recorded in different seasons or sites.

Forest type/location	Density (per m^2)	Author
Nothofagus, Victoria	847-2821	Howard 1975
Nothofagus, Tasmania	2022-3421	Howard 1975
Nothofagus, New South Wales	7868	Plowman 1979
Rainforest, Queensland	3210-115,470	Plowman 1979
Rainforest, Queensland	500-600	Jansen 1993
Rainforest, Queensland	260-640	Jansen 1997
Wet sclerophyll, Queensland	8050-105,940	Plowman 1979
Casuarina/Eucalyptus, New South Wales	14,887	Plowman 1979
Box-Ironbark, Victoria	116-255	This study

was employed allowing comparison with the present study. The density of invertebrates > 2 mm long varied with season and site from 52-144 per m^2 in rainforest in Queensland (Jansen 1997) compared with a seasonal variation of 27-91 per m^2 in the present study. In addition, there was a higher proportion of larger sized invertebrates in Queensland with 45% > 1 mm long compared with 13% in the present study, indicating that the dry mass of invertebrates was also considerably greater in the rainforests sites. Invertebrates ≥ 3 mm long were quantified in spring and summer in broad leaf litter in *Allocasuarina/Eucalyptus* woodland in Western Australia (Noack 1996 cited in Cale 1999). The densities were higher than in the present study with 36.3 per m^2 compared with 17.9 per m^2 in spring, and 9.3 per m^2 compared with 5.2 per m^2 in summer. However, both studies were relatively short-term and making comparisons of invertebrate densities from such limited time periods in areas where large variations in climatic factors such as rainfall could have a large effect may be misleading.

The information from within Australia suggests that leaf litter in box-ironbark forest supports relatively low densities of invertebrate prey for insectivorous birds such as the White-browed Babbler. Densities may also be low compared with forests outside Australia. Leaf litter invertebrate biomass in areas of Tennessee occupied by Ovenbirds *Seiurus aurocapillus*, a warbler that forages on leaf litter invertebrates (Smith and Shugart 1987), was 14 times greater than that in box-ironbark forest during the White-browed Babblers' breeding season in the present study. It was also six times greater than the peak invertebrate biomass recorded at Chiltern. Areas, which were judged to be unsuitable Ovenbird habitat because of low invertebrate density, still had a mean invertebrate biomass eight times greater than that in the box-ironbark leaf litter. In a second study in Ontario (Zach and Falls 1979), areas of deciduous forest avoided by Ovenbirds had invertebrate biomasses approximately equivalent to those in areas used by breeding White-browed Babblers in this study.

Direct comparisons are also possible with a study of Swainson's Warblers *Limnothlypis swainsonii*, another leaf litter forager, wintering in Jamaica (Strong and Sherry 2001). Invertebrate biomass in secondary forest leaf litter, a habitat considered marginal for the species as birds were unable to increase body mass before migration, was equivalent to the highest biomass recorded in this study during late winter and early spring. Thus, during the main period of the year, when White-browed Babblers attempt to breed, box-ironbark forest supported a biomass of leaf litter invertebrates that was equivalent to that judged to be adequate only for daily maintenance of non-breeding Swainson's Warblers.

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